INTERIM LOG GRADES FOR SOUTHERN PINE

(Based on unit value of yard lumber outturn)

DEVELOPMENT, ANALYSIS, QUALITY INDICES

A report of cooperative investigations conducted
by the following U. S. Forest Service agencies:

SOUTHERN FOREST EXPERIMENT STATION
SOUTHEASTERN FOREST EXPERIMENT STATION
REGION 8
FOREST PRODUCTS LABORATORY

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This report covers a cooperative investigation made by representatives of several U. S. Forest Service organizations* desiring to test, improve, and simplify systems of stratifying southern pine logs and trees into grades within which minimum variation would occur in the unit value of lumber yielded. Log grades were developed which provided a more accurate stratification into value groups than did any existing system. Specifications and procedure are briefly summarized on the 2 following pages. General considerations relating to the development and application of the grades are discussed beginning on page 4.

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(Based on unit value of yard lumber outturn)

Log	Any approximately cylindrical tree section. Common usage excludes pieces with length less than 8 feet or with average scaling diameter inside bark at small end smaller than 4-1/2 inches. Logs longer than 20 feet are beyond the scope of this table unless graded as several shorter logs.
Face	Any quarter-cylindrical surface running full log length.
Overgrown knot	Any invisible branch or stub buried beneath the log surface but indicated by a surface bump or disturbance of bark pattern.
Sound knot	Any visible branch, stub, or socket which contains neither advance decay extending to log heart nor any hole larger than 1/4 inch penetrating more than 2 inches (excludes defects defined in 1948 SPIB Rules paragraph 12d and 12e).
Unsound knot	Any visible branch, stub, or socket not conforming to definition of sound knot.
D	Average diameter of log inside bark at small end to nearest whole inch.
K	Number of overgrown knots plus sum of diameters of sound knots plus twice sum of diameters of unsound knots. Average diameter of knots should be measured to nearest whole inch at point where limb would normally be trimmed.
Sweep	Greatest deviation of longitudinal log axis from straight line connecting centers of each end of log. It should be measured to nearest whole inch, and is analogous to the middle ordinate of an arc.
Bad knot	Any visible knot which is so large that D is less than 6 times knot diameter, or any unsound knot.

Interim Southern Pine Yard Lumber Log Grade Criteria

Log grade	Minimum diameter and maximum aggregate knot criteria		
	With 4 visible faces	With 3 visible faces	With 2 visible faces
1	$D \geqq 17$ and $5K \leqq D$	$D \geqq 17$ and $7K \leqq D$	$D \geqq 17$ and $10K \leqq D$
2	$D \geqq 10$ and $2K \leqq D < 5K$	$D \geqq 10$ and $3K \leqq D < 7K$	$D \geqq 10$ and $4K \leqq D < 10K$
3	$D \geqq 5$ and $D < 2K$	$D \geqq 5$ and $D < 3K$	$D \geqq 5$ and $D < 4K$
4	$D \geqq 5$, but not qualified for higher grade after compliance with following degrade rules:		

(A) Degrade any log one grade if D equals or is less than 3 times sweep of at least 3 inches.

(B) Then degrade any non-Grade 4 log one grade if massed heart-rot hyphae visible on circumferential log surface suggest that fruiting has occurred or is imminent.

(C) Then degrade any Grade 3 log to Grade 4 if "bad knots" are too dispersed for containment in a 90 degree radial sector extending 1/4 of log length.

GRADING PROCEDURE

Grading southern pine logs on the basis of value yield per unit outturn of yard lumber depends largely on log diameter and the aggregate size and number of knots present. Log lengths must conform with local demands, but since random length lumber ranging from 8 feet to 20 feet long satisfies most orders for standard length yard lumber, log length has little utility in differentiating the value of yard lumber outturn from different logs with identical diameters and knot patterns. Size and/or number of knots admitted in a given grade of yard lumber depends on width of piece but not its length. Yard lumber logs shorter than 8 feet or longer than 20 feet are outside the scope of these grades, unless it is known that long logs will be bucked into shorter lengths prior to conversion; in this case, they should be theoretically subdivided so as to maximize volume in higher grades.

Example of 4-face grading procedure: Measure D; find K by accumulating the properly weighted knot count where necessary[1/]. The log should be tentatively classified as Grade 1 if D equals or exceeds both 17 and 5K. Failing this, the log should be tentatively classified as Grade 2 if D equals or exceeds both 10 and 2K. Otherwise, the log should be tentatively classified as Grade 3.

Tentative grade should be dropped to next lower grade if D equals or is less than thrice sweep (where sweep is at least 3 inches). Grade is again liable to being dropped one grade (but not below Grade 4) if massed heart-rot hyphae visible on circumferential surface suggest that fruiting has occurred or is imminent. As a final step, any logs still Grade 3 should be dropped to Grade 4 if "bad knots" are too dispersed for containment in a 90-degree radial sector extending 1/4 of the log length.

Grading procedure where K is accumulated from 3 faces or 2 faces is identical, except that 7K and 3K, or 10K and 4K will replace the 5K and 2K limits specified above.

1/ Obviously, it is not always necessary to make a knot count; training aids discussing shortcuts are now being prepared.

GENERAL CONSIDERATIONS

These interim log grades are based on the aggregate number and size of various kinds of knots relative to log diameter, with sweep, wood rot fruiting bodies, and excessive dispersion of large or unsound knots acting as degrading factors.

Length of log can be ignored as a criterion in grading logs 8-20 feet in length because there is no premium on board length of the great bulk of southern pine yard lumber which is sold in standard lengths (unlike the situation with regard to board width). Also, random lengths (allowing unlimited amounts of 10 to 20 foot lengths, and substantial amounts of 8 foot lengths) constitute a major outlet for standard length lumber. Hence, local custom and inventory dictate acceptable log lengths, and there is little economic incentive to manufacture long logs per se. In fact, there are definite disadvantages, since slab waste tends to increase with length, to say nothing about processing difficulties.

Furthermore, southern pine yard lumber is graded on the basis of usableness of the entire piece, rather than of cuttings. S. P. I. B. Standard Grading Rules for Yard Lumber allow wide boards (obtainable only from logs of large diameter) larger and/or more numerous knots than narrow boards in the same grade, but specifications are <u>not</u> similarly relaxed for long boards as compared to short ones. That is why log diameter but not length affects knot criteria. Since long boards or long logs are more apt to encounter degrading defect than short boards, it behooves the log makers to try to vary their lengths so as to segregate clear from knotty material as much as possible within the 10 to 20 foot range of log lengths. Thus, the only real reason for cutting long logs is to accumulate as much clear material in a good log as possible and to avoid mixing good with bad material. If 10 feet of clear material is mixed with 6 feet of very knotty material, poor log making is responsible for a low-grade log which will cut out low grade lumber.

Cull (except sweep) can be ignored as a factor affecting quality of sound yard lumber recoverable from a log because what sound lumber remains does not tend to be consistently better or worse than the average for the log grade. Sweep, however, does tend to degrade residual sound lumber by causing the knotty heart center of the log to appear in a greater proportion of the boards than it would have if the log had been straight. The serious effect of cull on costs and profit (but not lumber grade outturn) is discussed later, and a method of calculating maximum economically tolerable cull percent within grade for a particular locality is explained.

The log grades should satisfactorily stratify lumber values yielded by any species of southern pine manufactured into standard yard lumber. Local mill scale studies are needed, however, to validly estimate local lumber recovery and quality index by grades for the various species. Such grade yield studies have already been conducted by the Southeastern Forest Experiment Station in the shortleaf-loblolly pine types in the southern Piedmont and the central Atlantic coastal plain 2/.

When using this log grading system, logs may be graded by examining 2, 3, or 4 faces. Results will be reasonably comparable unless there is a tendency to always include or exclude the worst faces from the selected faces. The 4-face basis is the most consistent and should be used whereever the cost of doing so is not excessive. Frequently, however, yarded or decked logs cannot be cheaply turned, so 2- or 3-face grading will be preferable. Also, in certain types of reconnaissance, it is much more efficient to examine 2-faces on a maximum number of sample trees without walking to each tree than to examine 4-faces on many fewer sample trees.

DIAGRAMMING LOGS AND TALLYING YIELD

Numerous different grading systems for southern pine logs have been devised by different individuals using personal observation and opinion as a basis. Such systems usually answered immediate local needs for stratifying logs by the quality of lumber produced, but no comparisons of the relative merits of different systems were possible until sawed and graded lumber outturn could be ascertained for the same group of logs graded by several different systems independently of sawed outturn.

To allow such comparisons, some 1,296 logs were individually diagrammed and their graded yields of lumber were tallied during mill scale studies at the Santee and the Hitchiti Experimental Forests. All 4 faces of each log were diagrammed separately to show location, size, and character of every external imperfection that might possibly affect the grade of lumber yielded. Diagramming followed felling and bucking, with each tree, log, and diagram being numbered to allow subsequent lumber yield from each log to be identified with the proper diagram and

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2/ At the Hitchiti Experimental Forest near Macon, Georgia, and at the Santee Experimental Forest near Charleston, South Carolina.

tree. Lumber width, length, thickness, and grade of each item sawn was tallied separately for each numbered log. 3/

EXPRESSING RELATIVE VALUE OF LUMBER YIELD BY QUALITY INDEX

Grade-width-thickness value indices for shortleaf pine lumber were developed to take advantage of the reasonably constant relative price structure which prevailed from 1915 to 1949 (excepting OPA years). These indices (given in Table 1 of the Appendix)are merely the percentage relationship which various average item prices have borne to the price of a No. 2 Common standard length 1" x 8" kiln dried S4S board. That price was chosen for a base because no other item and grade so nearly bisects arrayed volume and value production, and because the marginal cost of lumber production has tended to fluctuate about this price. By means of these indices, a single value for each log can be calculated which is proportional to the average value per thousand board feet of dry lumber secured from the log. An illustration of how the quality index for an individual log was obtained is given below:

Log No. 1 (10.1" d.i.b., 16' long)

Grade	Thickness Width Inches	Lumber Tally Bd. Ft.	Lbr. Value Indices (Table 1, Appendix)	Weighted Indices
C	1 x 4	5.3	180	954
# 1	1 x 6	24.0	155	3,720
# 1	1 x 4	5.3	155	822
# 2	1 x 4	10.7	85	910
		45.3		6,406

$$\text{Mill tally quality index for log} = \frac{6,406}{45.3} = 141$$

Had the log cut out all Number 2 Common lumber in widths more than 4 inches and less than 12 inches, the log quality index would have been 100.

3/ Acknowledgment is made to the Southern Pine Inspection Bureau for providing lumber grading services during the Hitchiti study.

ANALYZING AND COMPARING EXISTING LOG GRADING SYSTEMS

All of the log diagrams were graded according to the specifications of two existing log grading systems. These are the modified Crossett system of log grades (revised by R. R. Reynolds in August 1949, Table 5 of Appendix) and the modified Southern Pine Association System of log grades (revised by E. J. Schlatter in August, 1949, Table 6 of Appendix). The log data were punched on cards, tabulations essential to index variance calculations for the two systems were run, and a detailed analysis of the data was made. It was found that there was no significant difference in precision between the two systems, although each had some strong points and some weak points. Formula used to calculate variances are given in Table 7 of the Appendix.

DEVELOPING THE INTERIM LOG GRADES

The log diagrams were sorted by diameter and arrayed by quality index within diameter groups. Log number, diameter inside bark, quality index, and diagram grade under each proposed log grading system were then listed. From this array, misclassifications or erroneous quality predictions made by each system could be easily spotted.

A log grading system was sought which would combine strong points and remedy weak points of the various systems but which would at the same time simplify the grading process. An exhaustive study of the 1,296 log diagrams showed how various log characteristics affected quality index. Criteria best correlated with log quality were combined into a grading system which, after numerous tests and simplifications, became the interim southern pine log grading system outlined in this publication.

ASSESSING RELATIVE MERITS OF VARIOUS LOG GRADING SYSTEMS

An objective test of log grade stratification by the several grading systems was made by employing analysis of variance. The pooled within-grade variances of the systems tested are given in Table 2 of the Appendix for the log populations of both Santee and Hitchiti mill scale studies. It is obvious that the interim log grades provide a less variable value classification for a group of logs than do the other systems.

Logs are not, by nature, separated into distinct and independent quality classes, but rather are found at all stages, ranging from a small, infinitely rotten, knotty, crooked log to a huge, sound, straight log without any knots from pith to bark. Hidden defects often cause lower grade lumber yields than might be indicated by external appearances; less frequently, logs will cut out better than external appearances indicate. Therefore, no arbitrary classification based on external appearances could be perfect. There will always be some misclassifications, especially near the dividing line between grades. That the recommended grades have reduced misclassifications considerably may be inferred from their highly significantly lower within-grade variance.

OBTAINING LOCAL QUALITY INDICES BY LOG GRADE

The average quality indices by log grade for the shortleaf-loblolly pine types of the southern Piedmont and the central Atlantic coastal plain have been sampled and are given in Table 3 of the Appendix.

In other pine types, or in similar types in different locations, local mill-scale studies should be conducted to get an unbiased estimate of the average quality indices by log grade. Aggregate lumber tallies by grade, thickness, and width of the lumber sawed from about 50 representative logs within each of the 4 recommended log grades should suffice. Using the lumber quality indices from Table 1 of the Appendix in conjunction with the recorded lumber grade tallies, and following the example given on page 6 of the text, the weighted indices for each group of logs can be found. Totalling the lumber tallies and weighted indices for the group of logs of a given log grade and dividing the index total by the tally total will give the average quality index for that log grade.

In the absence of local sampling, the average indices given in Table 3 of the Appendix may be used, but there is always the chance that an unsuspected local bias may exist. As can be seen from Table 3, there was little difference between Santee and Hitchiti grade indices except for the highest grade, represented by only 2 small logs on the Hitchiti.

CONVERTING QUALITY INDICES TO DOLLAR VALUES PER MBM

Log quality index may be translated to value according to any appropriate lumber price list by multiplying the index by a Value Factor. As long as the lumber price structure maintains proportionality with the index structure, the Value Factor may be simply calculated by dividing the appropriate price per MBM for No. 2 Common (1" x 8") by 100. If the

price of No. 2 were $72.00 per MBM, the Value Factor would be .72, and the dry lumber yielded by a group of logs with mill tally quality index of 150 would be estimated to be worth (.72)(150) = $108.00 per MBM lumber tally. Where it is known that the lumber price structure is somewhat warped as compared with the index structure, the Value Factor calculations should take into consideration prices and expected proportions of other important items besides No. 2. Table 4 of the Appendix illustrates the longer procedure, although in the example shown price and index structures are sufficiently similar so that the price of No. 2 alone would have given satisfactory results. Any locally or regionally valid price schedules and expected proportions might have been used in place of those chosen for the example.

In appraisal work, it may be desirable to convert realization value per MBM lumber tally, obtained as above, to value of lumber manufactured per MBM log scale (net scale or gross scale, as desired). This may be done in the usual fashion by multiplying values per MBM lumber tally by a Log Scale Factor equal to $\frac{\text{mill tally}}{\text{log scale}}$ and appropriate to the operation under consideration. Table 4 of the Appendix illustrates how it would work in case a 5 percent overrun was expected. Actually, the Santee experienced an 11 percent underrun and the Hitchiti a 2 percent underrun from net International scale (1/4-inch kerf), giving Log Scale Factor of .89 and .98 respectively. Where feasible, these local factors should be sampled for each log grade separately, as they tend to vary by grades.

The value of lumber manufactured per MBM log scale can be reduced by costs of various operations incidental to logging or milling and by appropriate margins for profit and risk; the reduced value would be a fair appraisal of log or tree worth per MBM log scale at any stage prior to that of finished lumber.

CULL AND MERCHANTABILITY

Since the amount of cull (except sweep) has no noticeable effect on the quality of sound material remaining in the log, cull (except sweep) can be ignored in grading pine logs according to the quality of sound lumber yielded. Any diminution in the amount of sound lumber recoverable from a log of a given size, however, increases the costs of logging and milling per unit of sound lumber recovered. In fact, the cost per MBM net log scale for logging or milling a defective log of given size is the usual cost per MBM gross scale for a sound log of that size multiplied by the ratio $\frac{\text{gross scale}}{\text{net scale}}$. Hence, log merchantability or profitability is distinctly affected by cull, though log quality

index or grade is not. In general, grade 1 logs can be profitable and yet possess a smaller proportion of sound scale than can grade 2, 3, and 4 logs. Cull, then, decreases profits by increasing costs per unit of sound lumber manufactured rather than by decreasing realization value per unit of sound lumber manufactured. This fact is often not understood by individuals when grading logs on the basis of the quality of sound lumber yielded.

In addition to predicting the quality of sound lumber yielded, however, quality indices can be used to calculate the maximum cull economically tolerable in any given log grade. Such figures, however, are only valid for a particular operation in a specified stand at a specified point in time. A hypothetical illustration of the "break even" calculation is shown below. The cost index for a given log grade is the quotient of the estimated current cost (stump to lumber yard) per MBM lumber tally for lumber manufactured from an average completely sound log in a given log grade, divided by the current price per MBM of No. 2 Common 1" x 8" standard length yard lumber (or the same base as used in quality index). The cost index divided by the quality index is subtracted from 1 to get the maximum locally tolerable cull percent for each grade; this will fluctuate as the ratio of cost to lumber price fluctuates--a fact well known to mill men.

Log grade	Cost index	Quality index	Max. tolerable cull percent
1	60	240	75
2	80	190	58
3	90	140	36
4	90	100	10

APPENDIX

Table 1. --Grade-width-thickness quality indices for shortleaf yellow pine lumber.

Table 2. --Comparison of pooled within-grade variances of several southern pine log grading systems tested at two locations.

Table 3. --Average log quality indices of interim yard lumber log grades in shortleaf-loblolly pine types.

Table 4. --Conversion of quality index to value per MBM.

Table 5. --Crossett Log grades for southern pine.

Table 6. --SPA log grades for southern pine.

Table 7. --Variance formulae

Table 1. --Grade-width-thickness quality indices for shortleaf yellow pine lumber

Nominal inches thickness	Grade	Nominal inches width				
		4	6	8	5 and 10	12
1	B and B	220	220	220	235	310
	C	180	180	180	200	245
	#1	155	155	155	165	200
	#2	85	100	100	100	115
	#3	60	80	85	85	85
	#4	45	45	45	45	45
5/4, 6/4, 7/4	B and B	240	240	240	280	340
	Other	Indices same as for corresponding width and grade of 1-inch material.				
2	B and B	265	260	260	280	340
	#1D	110	100	105	115	130
	#2D	100	90	95	100	110
	#3D	65	65	65	65	65
3 or more	#1 Tbr.	105	105	105	125	135
	#2 Tbr.	90	90	90	100	120

Basis: 8-20 ft. lengths for timbers, 16 ft. length for dimension, standard lengths for others. RG for timbers, KD and S4S for other No. 2 or better material, AD and S4S for other material. Index base is No. 2 common 1" x 8" board price, equivalent to 100 in the above table. Lumber grades are those of the Southern Pine Inspection Bureau of the Southern Pine Association, New Orleans, Louisiana.

Supporting data on which indices were based is given in mimeographed report to Southern Pine Log and Tree Grade Committee of July 22, 1949, designated RS-SS, MENSURATION, Tree Studies, Pine Log and Tree Grades, by L. R. Grosenbaugh.

Table 2. --Comparison of pooled within-grade variances of several southern pine log grading systems tested at two locations

System of log grades employed for southern pine	Pooled variances of index within grades for 865 Santee logs	Pooled variances of index within grades for 431 Hitchiti logs
Crossett (4-face)	1055	582
SPA (4-face)	1050	655
Interim (2-face)	732	435
Interim (4-face)	718	360

The ratio of any 2 independent variances each involving 861 degrees of freedom might reach 1.143 about 5 percent of the time and 1.209 about 1 percent of the time because of random sampling variation alone. Where each variance has only 427 degrees of freedom, the ratio of any 2 independent variance might reach 1.192 about 5 percent of the time and 1.284 about 1 percent of the time because of random sampling variation alone.

Using this normal variance ratio distribution as a criterion, the Interim log grades appear to be a highly significantly superior stratifying mechanism when compared with either other system at either Santee or Hitchiti. There are no significant difference between Crossett and SPA variances at either Santee or Hitchiti. Variances at Santee are greater than at Hitchiti because the range in quality and size of timber was greater at Santee. Although variances for 2-face grading at Santee are greater than comparable variances for 4-face grading the sampling was not intensive enough to show the significant differance which was shown at Hitchiti. In general, it may be expected that grading by 4 faces is the most accurate, followed by 3-face and 2-face grading in that order.

Table 3. --Average log quality indices of Interim log grades in shortleaf-loblolly pine types (based on mill tally)

Interim log grade	Log quality indices	
	865 Santee logs in central Atlantic coastal plain	431 Hitchiti logs in southern Piedmont
1	244	214
2	189	188
3	142	145
4	107	118

N. B. Logs graded at Santee or Hitchiti tended toward the above values whether graded by 2, 3, or 4 faces. Santee trees were forest-grown and included both larger and more defective timber than did Hitchiti old-field stands.

Table 4.--Conversion of quality index to value per MBM of mill tally or log (illustrated by using actual 1949 price schedule from a specific mill)

Important items	(Wt.)	x	Table 1 quality index	=	Wtd. index	(Wt.)	x	1949 lumber selling price	=	Wtd. price
B and B (1" x 6")	1	x	220	=	220	1	x	$165.	=	$165
#1 (1" x 6")	2	x	155	=	310	2	x	$105.	=	$210
#2 (1" x 8")	3	x	100	=	300	3	x	$ 72.	=	$216
#3 (1" x 6")	1	x	80	=	80	1	x	$ 60.	=	$ 60
#1 (2" x 4")	1	x	110	=	110	1	x	$ 77.	=	$ 77
#2 (2" x 4")	2	x	100	=	200	2	x	$ 70.	=	$140
Total	10				1,220	10				$868

The relative proportion of expected outturn of each important item determines the weight assigned to it. Value Factor = $\frac{\$868}{1,220}$ = .71148 dollars per index unit. Since the above price structure conforms fairly well with the index structure, the simple calculation of Value Factor = $\frac{72}{100}$ = .72 would be quite satisfactory. Items and weights may be varied to agree with proportions expected in specific mill outturn, but the above items and weights are suitable for most second-growth stands in board and dimension mill territory, according to Southern Pine Lumber Exchange data for 1939-41.

If the mill tally quality index of a group of logs were 150, and if the Value Factor were .72, the expected value would be (.72)(150) = $108.00 per MBM lumber tally.

If it is desired to convert mill tally quality index or value per MBM lumber tally to log scale quality index or dollar realization per MBM log scale, multiply by a Log Scale Factor = $\frac{\text{mill tally}}{\text{log scale}}$. Thus, if the Log Scale Factor for a mill were $\frac{1,050 \text{ bd. ft. lumber, mill tally}}{1,000 \text{ bd. ft. log scale}}$, and the mill tally quality index were 150, the log scale quality index would be (1.05)(150) = 157.5 and a lumber realization of (.72)(157.5) or (1.05)($108.00) = $113.40 would be secured from 1,000 feet of log scale, where a Value Factor of .72 was appropriate.

Table 5. --Crossett log grades for southern pine (revised by Reynolds, 1949). (Logs 10 ft. in length and over.)

Log d. i. b. intervals in inches	Knot d. i. b. intervals in inches	Limiting number of knots Grade 1	Limiting number of knots Grade 2	Limiting number of knots Grade 3
8 - 10	0 - 2 (1)	XXXXX	Unlimited	Unlimited
	2 - 5	XXXXX	1 (3)	Unlimited (2)
	5 - larger	XXXXX	1 (3)	Unlimited (4)
10 - 14	0 - 2 (1)	0	Unlimited	Unlimited
	2 - 5	0	1 (3)	Unlimited (2)
	5 - larger	0	1 (3)	Unlimited (4)
14 - 16	0 - 2 (1)	0	***** (5)	Unlimited
	2 - 5	0	1 - 6 (3)	Unlimited (2)
	5 - larger	0	1 (3)	Unlimited (4)
16 - larger	0 - 2 (1)	*****	***** (5)	Unlimited
	2 - 5	0 - 3	4 - 6	Unlimited (2)
	5 - larger	1	0	Unlimited (4)
Max. total cull (inc. sweep)		50%	40%	20%

Degrade any log one grade if there is evidence that Fomes pini pierces bark surface.

Degrade #1 log to #2 if sweep is 20-40%. Degrade #1 log to #3 if sweep 40-50%.

Degrade #2 log to #3 if sweep is 20-40%.

Total cull (inc. sweep) will not affect grade of log, except to make it completely unmerchantable.

(1) Except that adventitious buds, branches, or knots are ignored.
(2) Except no more than 2 complete whorls allowed.
(3) If otherwise perfectly clear log.
(4) If restricted to 3 faces or a single terminal 4 ft. of all faces.
(5) Unlimited 0 - 2 inch knots if no 2 - 5 inch knots are present.

*****Two 0 - 2 inch knots may be substituted for any portion of permissible 2 - 5 inch knots.

NB (Limits separated by boxes are alternative and mutually exclusive.
(Limits joined by boxes are concurrent or simultaneously permissible.

Table 6. --SPA log grades for southern pine (revised by Schlatter, 1949)

Log D. I. B. interval in inches	Grade criteria	Limits Grade 1	Limits Grade 2	Limits Grade 3	Limits Grade 4
7-1/2 - 9-1/2	Sound knotty faces	XXXXX	XXXXX	0 - 2	Unlimited
	Small sound knots	XXXXX	XXXXX	Unlimited	Unlimited
	Large sound knots	XXXXX	XXXXX	0	Unlimited
	Concurrent defects	XXXXX	XXXXX	0 - 2/3 cull (inc. sweep)	0 - 2/3 cull (inc. sweep)
		XXXXX	XXXXX	No unsound knots	Unlimited small unsound knots
9-1/2 - 16-1/2	Sound knotty faces	XXXXX	0 *	1 - 2 *	Unlimited
	Small sound knots	XXXXX	*	Unlimited **	Unlimited
	Large sound knots	XXXXX	*	Unlimited	Unlimited
	Concurrent defects	XXXXX	0 - 2/5 cull (inc. sweep 0 - 4")	0 - 2/3 cull (inc. sweep)	0 - 2/3 cull (inc. sweep)
		XXXXX	No unsound knots	No unsound knots	Unlimited small unsound knots
16-1/2 - Larger	Sound knotty faces	0 *	1 *	2 *	Unlimited
	Small sound knots	*	*	Unlimited **	Unlimited
	Large sound knots	*	*	Unlimited	Unlimited
	Concurrent defects	0 - 1/5 cull (inc. sweep 0 - 4") 1/2 twist per 16 ft., No unsound knots	0 - 2/5 cull (inc. sweep) No unsound knots	0 - 2/3 cull (inc. sweep) No unsound knots	0 - 2/3 cull (inc. sweep) Unlimited small unsound knots

Grade criteria

Face = one of the quartered cylindrical surfaces running full length of log.

Small knot = knot with D. I. B. between limits 1/2 inch - 1/4 log D. I. B. or 4-1/2 inches (whichever is smaller).

Large knot = knot with D. I. B. larger than above limits.

* In addition, a small knot is allowed on a single otherwise clear face, or else any number of any size knots are allowed in terminal 2 feet of a single otherwise clear face.

** If located on terminal 2 feet of a single face.

General - Limits separated by boxes are alternative, not concurrent.

Limits joined by boxes are concurrent.

Drop Grade 1 and Grade 2 logs one grade if they have less than 4 rings per inch for more than 1/3 of diameter on either end.

Table 7. --Variance formulae

(Assuming variance of $f_i x_i$ within grade is proportional to f_i, and that L_i is proportional to population values.)

N = Number of grades or strata in a given system.

K_i = Number of logs in i^{th} grade.

f_i = Lumber tally of a given log in the i^{th} grade.

$\bar{f}_i$ = Lumber tally of mean log in the i^{th} grade.

$\bar{\bar{f}}$ = Lumber tally of mean log in entire system.

$$L_i = \frac{K_i}{\sum^{N} K_i}$$

$$P_i = \frac{\sum^{K_i} f_i}{\sum^{N}\sum^{K_i} f_i} = \frac{L_i \bar{f}_i}{\bar{\bar{f}}} = \frac{K_i \bar{f}_i}{\bar{\bar{f}} \sum^{N} K_i}$$

x_i = Unit quality index of a given log in the i^{th} grade.

$f_i x_i$ = Unit quality index of a given log in the i^{th} grade weighted by lumber tally.

$\bar{x}_i$ = Unit quality index of mean log in the i^{th} grade.

$\bar{\bar{x}}$ = Unit quality index of mean log in entire system.

V_{x_i} = Variance of unit quality index in i^{th} grade.

$$= \left[\frac{K_i}{K_i - 1}\right]\left[\frac{\sum f_i x_i^2}{\sum f_i} - \left(\frac{\sum f_i x_i}{\sum f_i}\right)^2\right] = \frac{\sum f_i x_i^2 - \frac{(\sum f_i x_i)^2}{\sum f_i}}{(K_i - 1)\ (\bar{f}_i)}$$

$\bar{f}_i V_{\bar{x}_i}$ = Variance in quality of mean log in i^{th} grade with weight $\bar{f}_i$.

$$= \frac{\sum f_i x_i^2 - \frac{(\sum f_i x_i)^2}{\sum f_i}}{(K_i - 1)\ (K_i)}$$

$$V_{\bar{\bar{x}}} = \frac{\sum^{N} L_i^2 \bar{f}_i V_{\bar{x}_i}}{\bar{\bar{f}}} = \frac{\sum^{N} L_i \bar{f}_i V_{x_i}}{\bar{\bar{f}} \sum^{N} K_i} = \frac{\sum^{N} P_i V_{x_i}}{\sum^{N} K}$$

$$V_x = \sum^{N} P_i V_{x_i}, \text{ approximated by } \frac{\text{Pooled}\left[\sum f_i x_i^2 - \frac{(\sum f_i x_i)^2}{\sum f_i}\right]}{\text{Pooled}\left[(K_i - 1)\ (\bar{f}_i)\right]}$$